Hi this is Steve Nerlich from Cheap Astronomy www.cheapastro.com and this is *It's all downhill from here.*

Folks, the whole universe is going to pot. Even when our universe burst upon the scene 13.7 billion years ago, much of that initial burst quickly dissipated into relic neutrinos and cosmic microwave background photons – and ever since, pretty much everything our universe has done has just dissipated more energy. So, despite the occasional enthusiastic outburst of supernovae and other celestial extravagances, it's becoming increasingly apparent that our universe is getting on a bit.

The second law of thermodynamics (the one about entropy) demands that everything goes to pot over time – since pretty much anything that happens is an opportunity for energy to be dissipated.

Now, dissipation doesn't mean you lose energy. The universe is currently full of energy and should always retain the complement of energy that it started with. But… that energy can only make something interesting happen if it's in a degree of thermal disequilibrium. For example, if you take an egg out of the refrigerator and drop it in boiling water, it cooks. A useful and worthwhile activity, even if not a very efficient one – since lots of heat from the stove just dissipates into the kitchen, rather than being retained for the cooking of more eggs.

But, if you drop an already cooked, already heated egg into the same boiling water… well, what's the point of that? No useful work is done, indeed nothing of note really happens because the egg and the water are already close to being in thermal equilibrium.

This is roughly the idea behind increasing entropy. Everything of note that happens in the universe involves a transfer of energy and at each and every such transfer some energy is lost from the system that is doing work. This work might involve the Sun shining on plants to drive photosynthesis. This is useful work since the plants are now available to offer up energy by feeding something else , like us say, but, because the plants can't use every photon from the Sun, some of that solar energy is just lost by being reflected back out into space. Furthermore, us plant eaters are constantly radiating heat as a by-product of our metabolism - all of which is dissipated away, just adding an infinitesimal amount of extra heat to the wider universe.

So, following the second law to its logical conclusion, you'll eventually end up with a universe in thermal equilibrium with itself. All the energy of the universe is still there but spread out so evenly there are no disequilibrium gradients left to drive energy transfers to do useful work – or to cook eggs. Essentially, once you get to this point, nothing else of note will ever happen again – a state known as heat death.

This growing even spread of energy is arguably the outcome of an increase in randomness - which is an old fashioned definition of entropy. The idea of increasing randomness can be confusing though since an ultimate state of cosmic entropy is where everything is homogenous and isotropic and nothing much happens. So although the universe might currently appear to contain huge amounts of disorder and chaos - with supernovae explosions going off all over the place - all this dramatic activity is actually representative of a state of low entropy.

Now, it is thought that the early universe was initially in a state of thermal equilibrium, but there was also lots of gravitational potential energy around. So, matter (in both light and dark flavours) 'clumped' together – creating lots of localised thermal disequilibriums, like stars – and from there all sorts of interesting things were able to happen. But gravity's ability to contribute useful work to the universe also has its limits.

In a static universe, the end point of all this clumping would be a collection of black holes – which are considered to be objects in a state of very high entropy, since whatever they contain no longer engages in energy transfer. It just sits there – and, apart from some whispers of Hawking radiation, will just keep sitting there until eventually (in a googol or so years) those black holes will evaporate in a puff of dissipated energy.

It's possible to estimate the current entropy of our universe by tallying up its various components – which have varying levels of entropy density. At the top of the scale are black holes – and at the bottom are luminous stars. Luminous stars appear to be locally enthalpic – like, as we discussed, the Sun heats the Earth enabling all sorts of interesting things to happen. But this is still a time-limited process - and as we increasingly find more black holes ,including supermassive black holes at the centre of galaxies, we have to recalculate just how far the universe is down the long road towards heat death.

Current theory has it that our universe will probably expand forever and keep cooling down towards zero Kelvin in the process. But - at least as a thought experiment, we can imagine a closed universe that collapses back down into a Big Crunch - and which would still, nonetheless follow the second law of thermodynamics.

Already in our universe a lot of primeval hydrogen atoms have engaged in fusion reactions to form heavier elements. Gathering all that stuff back together as you move towards a Big Crunch won't produce a lot of new star formation since elements with atomic numbers greater than or equal to iron can't form luminous stars - so during a Big Crunch the dominant process is the formation of black holes - an indication that entropy has increased further down the line than when that closed universe was in its expansion phase.

So, if you like, an iron atom has a much higher entropy value than a hydrogen atom - since, a bit like a black hole, an iron atom has bound up most of the energy that it contains. This idea helps to explain yet another definition of entropy, which is that it represents a loss of free energy (that's energy available for work) from a system - or from a universe.

And a quick footnote here. A googol, the numbers of years it might take a black hole to evaporate due to proton decay, is $1x10^{100}$ - which is a one with a hundred zeros after it. And it's spelt goog*ol* - not *le*.

Thanks for listening. This is Steve Nerlich from Cheap Astronomy, www.cheapastro.com. Cheap Astronomy offers an educational website where we'll try to make the best of the time you have left. No ads, no profit, just good science. Bye.